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Assessment of the Effects of Oil on Arctic Marine Fish and Marine Mammals

L. Johnson

Western Region
Department of Fisheries and Oceans
Winnipeg, Manitoba R3T 2N6

November 1983

Canadian Technical Report of Fisheries & Aquatic Sciences No. 1200

Fisheries and Oceans   Pêches et Océans

Canada

Canadian Technical Report of Fisheries and Aquatic Sciences

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Canadian Technical Report of

Fisheries and Aquatic Sciences 1200

November 1983

ASSESSMENT OF THE EFFECTS OF OIL ON ARCTIC MARINE FISH AND MARINE MAMMALS

A Report Commissioned by

The Arctic Research Directors Committee

of the

Department of Fisheries and Oceans

and prepared by

L. Johnson
Western Region
Department of Fisheries and Oceans
501 University Crescent
Winnipeg, Manitoba R3T 2N6

with assistance from

E.B. Bennett, Bayfield Laboratory, OSS Central Region
E.M. Levy, Bedford Institute of Oceanography, OSS Atlantic Region
A.W. Mansfield, Arctic Biological Station, AFS Gulf Region

This is the 160th Technical Report
from the Western Region, Winnipeg

Cat. no. Fs 97-6/1200 ISSN 0706-6457

Correct citation for this publication is:

Johnson, L. 1983. Assessment of the effects of oil on Arctic marine fish and marine mammals. Can. Tech. Rep. Fish. Aquat. Sci. 1200: viii + 15 p.

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ABSTRACT

Johnson, L. 1983. Assessment of the effects of oil on Arctic Marine fish and marine mammals. Can. Tech. Rep. Fish. Aquat. Sci. 1200: viii + 15 p.

Arctic marine ecosystems are briefly reviewed to provide a background for the assessment of the effect of oil on Arctic marine fish and marine mammals; the probability of an oil spill in Arctic waters and its possible effects is developed through the provision of answers to a series of questions drawn up by the Commissioners of the Report. The important fishes in the marine environment are almost exclusively anadromous: Arctic charr, Salvelinus alpinus, and various whitefishes, Coregonus spp. As these species spawn and pass their earliest stages in fresh water they are not exposed to possible toxicants in the marine environment over the period of their greatest susceptibility. Arctic charr are widespread throughout the Arctic and therefore are likely to encounter any spills that approach the shoreline. The most vulnerable stocks are the whitefishes that occupy the Mackenzie Delta and the immature fishes that utilize the inshore waters of the Beaufort Sea in their passage to summer feeding and rearing grounds. The changing vulnerability of the bowhead whale, Balaena mysticetus, beluga, Delphinapterus leucas, and narwhal, Monodon monoceras, is considered along their seasonal migration routes; the locations at which young of these species are born, considered to be the most vulnerable phase in the life-history, are imperfectly known. Of the seals, ringed seal, Phoca hispida, is both the most widespread and probably the most susceptible to possible oil damage; this is particularly the case in winter when the seal is restricted to territories in which breathing holes are maintained in the fast ice, and in early spring when pupping and moulting takes place on the ice. Few specific effects of oil on marine mammals have been observed. The greatest danger is considered to be the accumulation of environmental perturbations each, in itself, of small, indefinable effect, but together generating "noise" in the energy flow path, creating increased variability and the possibility of the elimination of important stocks. The most vulnerable species from this perspective are considered to be the bowhead whale and the walrus, Odobenus rosmarus. It is unlikely that causes will be directly attributable to specific events unlesss effects are of catastrophic proportions. Recommendations for further study are made.

Key words: Arctic marine ecosystems; environmental assessment; ecosystem perturbation; oil spills; Arctic marine fish; Arctic marine mammals; oil in ice-covered waters.

RESUME

Johnson, L. 1983. Assessment of the effects of oil on Arctic Marine fish and marine mammals. Can. Tech. Rep. Fish. Aquat. Sci. 1200: viii + 15 p.

Ce rapport comprend une courte étude des écosystèmes marins de l'Arctique, laquelle permettra aux lecteurs de mieux apprécier les effets du pétrole sur les poissons et les mammifères des mers arctiques; il se demande s'il y a des chances qu'une fuite de pétrole se produise dans les mers de l'Arctique et il analyse les effets possibles d'un tel déversement en répondant à la série de questions posées par ceux qui ont demandé le rapport. Les poissons importants du milieu marin sont presque tous anadromes, tels l'omble chevalier (Salvelinus alpinus) et diverses espèces de corégones (Coregonus spp.). Comme ces poissons fraient en eau douce et y passent les toutes premières étapes de leur développement, ils ne sont pas exposés aux substances toxiques qui peuvent polluer le milieu marin au moment où ils sont le plus vulnérables. L'omble chevalier peuple la plupart des eaux de l'Arctique et serait fort probablement touché par un déversement de pétrole à proximité de la côte. Les espèces les plus menacées par la marée noire sont les corégones qui peuplent le delta du Mackenzie et les alevins qui traversent les eaux côtières de la mer de Beaufort en direction des eaux riches en nourriture où ils passent l'été. Le rapport traite aussi de la baleine boréale (Balaena mysticetus), du bélouga (Delphinapterus leucas) et du narval (Monodon monoceras), mammifères dont la vulnérabilité varie tout au long de leurs routes migratoires saisonnières; personne ne sait très bien où naissent les petits, étape du cycle biologique pendant laquelle ils sont le plus vulnérables. Chez les phoques, le phoque annelé (Phoca hispida) est à la fois le plus largement répandu et le plus susceptible de subit les effets néfastes des déversements de pétrole, particulièrement en hiver, lorsqu'il ne peut s'éloigner du trou d'air au'il se creuse dans la banquise côtière, et au début du printemps, lorsqu'il gagne les plages de glace pour mettre bas et muer. Nous connaissons peu des effets exacts du pétrole sur les mammifères marins. C'est en fait l'accumulation de perturbations environnementales qui pose le plus grand danger: prises individuellement, ces perturbations ont un effet négligeable, mais ensemble, elles occasionnent un "bruit" dans le transfert d'énergie qui fait croître la variabilité et pourrait entraîner l'élimination de stocks importants. La baleine boréale et le morse (Odobenus rosmarus) sont considérés comme étant les espèces les plus vulnérables à ce point de vue. Il est peu probable que l'on puisse attribuer directement tel effet à tel événement particulier à moins que les effets n'atteignent des proportions catastrophiques. On recommande l'approfondissement des études à cet égard.

Mots-clés: écosystèmes marins de l'Arctique; évaluation environnementale; perturbation de l'écosystème; déversements de pétrole; nappe de pétrole sur des eaux recouvertes de glace.

PREFACE

The Arctic Offshore Development Committee (ARCOD) of the Department of Fisheries and Oceans asked the Arctic Research Directors Committee (ARDC) for advice on the probable effects of oil on Arctic marine fish and marine mammals. ARDC convened a working group whose names and affiliations appear on the cover of this report. Dr. Lionel Johnson, the chairman, first prepared an extensive background paper dealing with the general and theoretical ecology of arctic ecosystems, the biological oceanography of the arctic, and the general biology of arctic marine fish and marine mammal stocks. That paper will be published independently by Dr. Johnson. It provided an excellent basis for the present report, and ARDC is grateful to Dr. Johnson for his efforts.

In a second stage of the study, the working group as a whole was given a set of questions to which the ARDC wished to have the best answers possible, given the present state of scientific knowledge. These questions were:

1. What are the probabilities of accidental release of oil as a consequence of oil exploration, production or transportation in Arctic waters? Give separate consideration to release in open water, in polynyas, under shore-fast ice or under pack ice.

2. What concentrations of oil fractions might be expected to occur in open water, under ice, in the plankton and in the benthos as a result of such releases and what would be the expected rate of change in these concentrations?

3. What would be the physiological and ecological consequences of such oil concentrations for fish and marine mammals that were in the area at the time?

4. Which stocks of fish and marine mammals are vulnerable to oil spills in the Arctic? Which stocks are especially sensitive for one or more of the following reasons: i) they are heavily exploited; ii) at some stage in their life history they occupy critical habitats e.g. breeding grounds or feeding grounds that might be impacted by oil, and iii) the species exhibits some critical physiological or behavioural sensitivity to oil?

5. Which stocks should D.F.O. seek to protect by requesting particular areas or types of habitat (e.g. polynyas, areas of permanent shore-fast ice) be protected from oil-related activities?

6. What kinds of observational programs would be required to detect: i) deleterious effects on marine fish or mammal stocks, and ii) the recovery of the ecosystem from the effects of an oil spill?

7. What kinds of preventive measures or countermeasures would be appropriate in respect of: i) chronic low-level pollution, ii) major spills, or iii) blowouts? In the event of a major spill or blowout, should D.F.O. seek to halt oil operations in the area until the system has fully recovered? If not what action is called for?

This report embodies the working group's answers to those questions. In addition, there is an executive summary, a concluding statement, and recommendations for further study. The document as a whole was drafted by Dr. Johnson, amended by the members of the working group and finally accepted, after further amendments, by the Arctic Research Directors Committee of D.F.O. The committee thanks Dr. Johnson and his committee for their work, and is confident that the report will be useful to D.F.O. and other organizations in the formulation of policies regarding the exploitation of oil in Arctic marine environments.

K.H. Mann

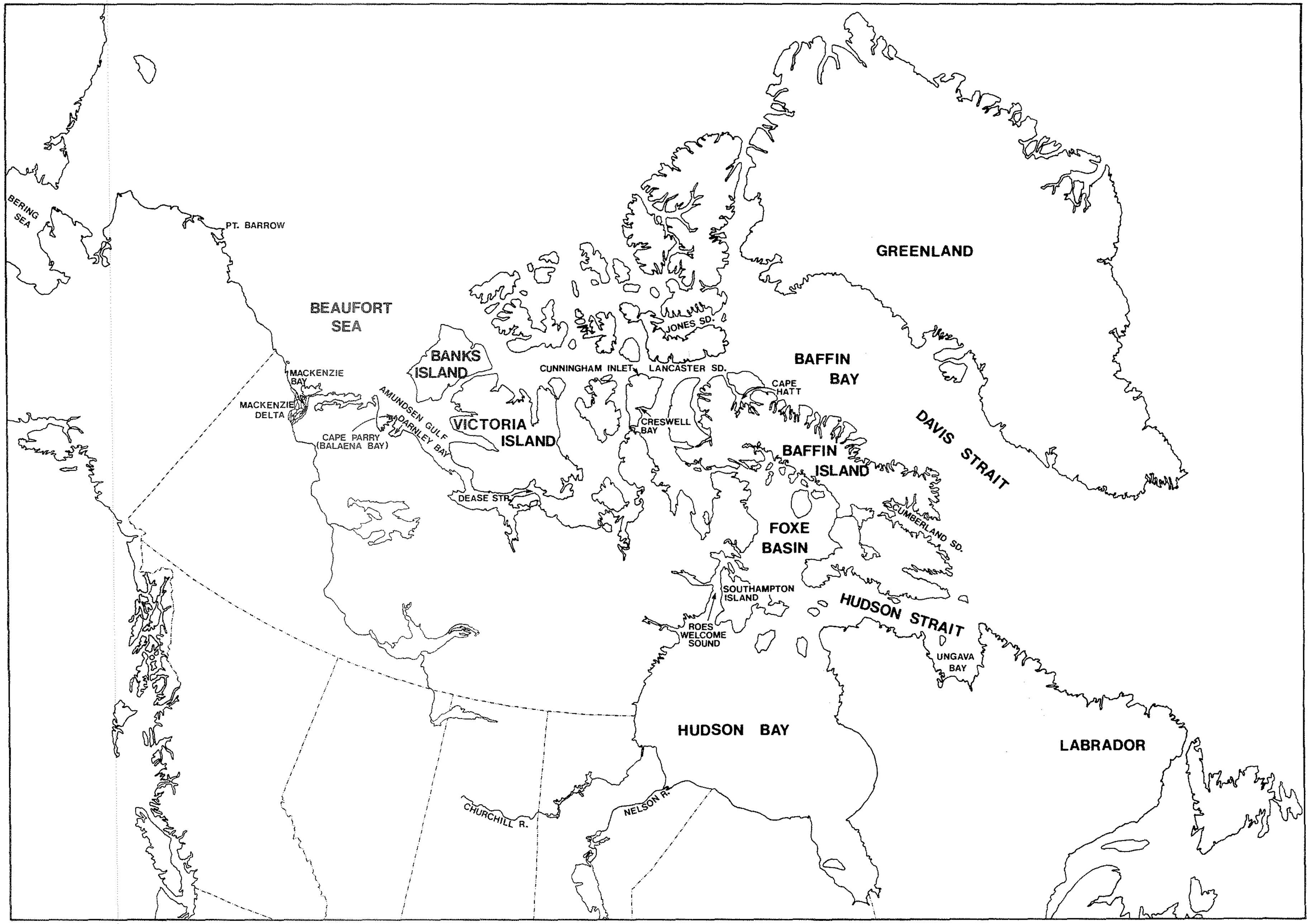
Chairman, Arctic Research Directors Committee

June 1983

"We cannot stop where we are, stuck with today's level of understanding, nor can we go back. I do not see that we have a real choice in this, for I can only see the one way ahead. We need science, more and better science, not for its technology, not for its leisure, not even for health and longevity, but for the hope of wisdom which our kind of culture must acquire for its survival."

Lewis Thomas

The Medusa and the Snail



Map of the Northwest Territories showing places mentioned in the text.

EXECUTIVE SUMMARY

The Arctic Ocean, when viewed in polar projection, can be seen as a northern Mediterranean. This sea between the land has a narrow, shallow exit through the Bering Straits to the Pacific and a wide deep connection to the North Atlantic between Greenland and Norway as well as a narrower one between Ellesmere Island and Greenland. As the free circulation of cold surface water is prevented by the constraining land masses much of the Arctic Ocean remains permanently ice-covered, although, even in winter, wind, currents and the earth's rotation maintain the ice in constant motion causing the formation of leads, tide-cracks and polynyas. Melting of the pack in summer is largely confined to the near-shore regions with the result that only about 10 percent of the ocean's surface area is ice-free, even at the height of the open-water season; climatic variability is such that this figure changes considerably from year to year.

The permanent ice-cover isolates the underlying waters from the turbulent effect of wind, inhibiting vertical circulation in the water column, while the presence of ice on the surface promotes stability still further through the maintenance of a constant temperature gradient. Together these factors create a very stable water mass that prevents the return of nutrients to the surface and hence greatly restricts photosynthesis (Dunbar 1960, 1968, 1970a, 1973, 1976, 1977, 1981, 1982). This low potential for primary productivity is further reduced by the light filtering effect of the ice itself, which may be from one to several metres thick. This results in a very low order of primary production: from 0.6 g C $m^{-2}yr^{-1}$ in the region of the North Pole to 70 g C m^{-2} yr^{-1} in the more southerly regions, such as Frobisher Bay (Grainger 1979).

Most of the production, both primary and secondary, occurs either in the benthic regions or on the under-surface of the ice (the so-called epontic biota) (Clasby et al. 1976; Horner 1977; Grainger 1977); production in the water column is extremely low. These conditions appear to be inimical to the development of truly pelagic stocks of Arctic marine fishes. Apart from the large numbers of aquatic birds that are dependent on marine resources, the terminal predators in the marine food chain are almost exclusively marine mammals.

Stocks of truly marine fish species, of potential commercial value are few and very localized. There are no endemic species of commercial value. Some stocks of Pacific herring, Clupea harengus pallasii, occur in the Mackenzie Delta region and eastwards along the northern continental coastline to Darnley Bay; capelin, Mallotus villosus, occur spasmodically, both in time and space, in northern Labrador, Hudson Bay and in the region of Bathurst Inlet in the Central Arctic; some stocks of Greenland halibut (turbot), Reinhardtius hippoglossoides, are encountered in deep water in Davis Strait and appear to have some commercial potential (Dunbar 1970b; McAllister 1975).

Otherwise the fishes of significance in the economy of the Arctic are anadromous. Broad whitefish, Coregonus nasus, lake whitefish, C. clupeaformis, and cisco, Coregonus spp., are all abundant in the Mackenzie Delta. Many of these populations utilize the inshore waters of low salinity of the Southern Beaufort Sea as a dispersal route to their summer feeding areas in coastal lakes and streams; many remain in these freshwaters over winter, emerging the following summer to return to the Delta.

Without doubt the most important species of fish in the Arctic is the Arctic charr, Salvelinus alpinus, in its anadromous form. Arctic charr spends its first four to eight years in freshwater before making its first migration to the sea when about 180 to 200 mm in length; after spending about 45 days in the sea charr return to fresh water to overwinter. This routine is repeated annually except that once every two to three (or even four) years mature fish may remain in fresh water to spawn. Downstream migration begins as soon as water starts to flow in the rivers in spring; there is a tendency for the large fish to move downstream first and for the first fish moving downstream to wander the furthest in the sea. In the sea the general tendency is for fish to remain relatively close to the stream from which they emerged in spring but examples of charr travelling up to 500 or 600 km are not uncommon. Usually charr remain in relatively shallow water close to the coast, but they are also known to have traversed deep open water, such as Dease Strait separating Victoria Island from the mainland. Fish wandering far from their home stream enter streams of opportunity in which to overwinter. It seems possible that the majority of fish return to their home stream to spawn, although direct evidence is very difficult to come by. Arctic charr appear to be well adapted to harvest the brief bloom of production occurring in the coastal waters of the Arctic in the open water period. Their food consists of a wide variety of organisms, but mainly various amphipods and small fishes. Having few natural enemies in the adult state, apart from man, charr is essentially terminal in the food chain (Johnson 1980).

The other terminal predators of great importance in the Arctic marine ecosystem are the marine mammals: seals, walrus and whales. Ubiquitous, and of great importance in the economy, is the ringed seal, Phoca hispida. This is the species most closely adapted to ice-covered waters, maintaining breathing holes in the ice throughout the winter; this is the only species that regularly maintains access to the air in this manner. These holes can only be maintained in first-year ice; as a consequence the distribution of adult seals is largely restricted to bays and indentations of the coastline where land-fast ice forms. Juvenile ringed seal usually seek access to the air above leads and polynyas rather than maintaining their own breathing holes. Second in its close association with ice is the bearded seal, Erignathus barbatus, followed by walrus, Odobenus rosmarus (Mansfield 1958, 1973). Both bearded seal and walrus tend to aggregate more than ringed seal, being attracted to the open waters of leads and polynyas (Stirling and Cleator 1981); walrus in particular possesses a considerable capacity for breaking ice that has newly formed. The harp seal, Pagophilus groenlandicus, moves out of the Arctic in winter, migrating south to localized regions of suitable ice-cover in the Gulf of St. Lawrence and on the Newfoundland 'Front' to whelp in early spring before migrating northward as the waters open up.

The large whales, too, move out of the most solidly frozen areas in winter to the more open pack-ice on the fringes of the region where ice and open water meet. The narwhal, Monodon monoceras, stays in the heaviest pack in Davis Strait where ice cover may be over 90 percent (Finley and Renard 1980). In spring narwhal move north and west into the eastern part of the Archipelago but seldom move into the central and western Arctic (Mansfield et al. 1975) on account of late break-up of the ice in this region. The beluga (or white whale) Delphinapterus leucas, and the bowhead whale, Balaena mysticetus, are both represented in the Arctic by eastern and western stocks, but there is virtually no intermingling of the stocks in the central region. The western stock of both species moves from the pack ice of the Bering Sea, where they overwinter, to the north and east into the Beaufort Sea, utilizing leads in the shear zone created by the Beaufort Gyre; they then turn south to the Amundsen Gulf (Fraker 1979). As the open water season progresses they move along the Beaufort Sea coastline to the Mackenzie Delta. Beluga spend considerable time in this area before returning to the Bering Sea. The eastern Arctic stocks are found on the fringes of the pack-ice in Davis Strait in February and March but in waters less heavily encumbered with ice than those occupied by the narwhal; again in spring they move into the eastern part of the Archipelago as the water opens up.

The two sub-systems of greatest importance, as they provide the driving mechanism for these higher trophic levels, are the benthic and epontic associations. The benthic organisms of particular importance are the bivalves that are the major food resource of the bearded seal and walrus. These bivalves occupy extensive beds between the lower limit of ice-scour (3 - 10 m) and a depth of about 300 m. The epontic biota is sustained by the growth of algae attached to the underside of the ice. Amphipods and copepods rely on this algal growth and, in turn, maintain a large, if widely distributed, population of Arctic cod, Boreogadus saida. Arctic cod live in the crevices and undulations of the underside of the ice; they seldom grow very large, only infrequently reaching 250 mm. This epontic biota is essentially transient, being built up in the three to four months prior to break-up; inevitably at break-up the biota is dispersed. The ice-edge, as it moves inward to the central region, is one of the most significant feeding areas for birds, fishes and marine mammals (Bradstreet 1982; Bradstreet and Cross 1982).

Development of the oil industry in Arctic marine waters poses a potential threat to the fishery resource of the region in so far as both the physical and chemical effects of oil have been shown to be detrimental to ecosystems that have been contaminated. The projected investment of some ninety billion dollars (Blair and Carr 1981) in oil exploration and development over the next decade has the potential for causing great environmental change.

In temperate regions, where most studies have been conducted, there is general agreement that it is the shoreline and sub-littoral ecosystem that suffer most from the effects of an oil spill. On the high seas oil spills appear to have little detectable effect. However, it is recognized that, to be detectable, the effect on the biota would have to be enormous before it could be firmly attributed to oil. Pari passu, the sampling effort necessary to identify the population changes taking place against a highly variable natural background would have to be of unprecedented proportions.

At present, our knowledge of the fate of oil and the toxicity resulting from crude oil spills in cold waters is inadequate to address the problem in detail. However, high seas in the Arctic scarcely exist; most drilling sites and transportation routes are located sufficiently close to shore, either along the mainland coast, or between the islands of the Archipelago, to ensure that any oil spilt has a high probability of coming into contact with the shoreline soon after release. Oil spilt in open water rapidly loses the more volatile components which, in general are the most toxic. Oil spilt under the ice, resulting from a blowout or pipeline fracture, will accumulate on the under-ice surface. In winter this oil becomes encapsulated by ice forming below the 'moon pool', ultimately being released to the surface in the following spring and summer when the ice fractures and melts. Encapsulated oil will not lose its more volatile fractions until exposed to the atmosphere at the time of melting; unweathered oil could therefore be released at the ice edge where biological activity is greatest.

Before the effect of any disturbance can be assessed it is essential to have broadly based knowledge of the system likely to be affected. This information is difficult to obtain, particularly in the Arctic where the normal difficulties of marine sampling are compounded by the long period of total darkness in winter, bad weather and the capacity of ice to obscure the animals and restrict the operation of sampling gear.

In monetary terms the value of the marine fisheries in the Arctic, including both true fishes and marine mammals, is not high when compared with the marine fisheries of the east and west coasts of Canada; in cultural terms and with respect to meeting the subsistence needs of the Indian and Inuit population their importance is clearly very great. Loss of, or significant reduction in, these stocks would cause great distress apart from the biological implications of such a catastrophe.

The species of greatest economic significance, ringed seal, the coregonids, lake whitefish and ciscos, and Arctic charr, are the species most likely to be exposed to the effect of an oil spill. The stocks of these species appear to be generally withstanding current levels of exploitation without significant change, although certain charr stocks, particularly in the vicinity of settlements, are in a depressed state and appear to be maintained in this state by relatively light harvesting. The life-history and migration pattern of the Arctic charr and the coregonids ensure that the most susceptible stages, eggs, alevins and fry, are not exposed to contamination in the marine environment, as they all occur in freshwater.

Ringed seals, particularly adult males and juveniles, have been shown to fluctuate considerably in abundance in the natural state, apparently as a result of fluctuations in the abundance of food. A damaging oil spill at the time when the stocks are low could, conceivably, cause a reduction in breeding stock that would necessitate a long recovery period before the original levels of abundance could be reestablished.

The fish stocks most likely to be affected by oil spills utilize the coastal waters of the Beaufort Sea and the Mackenzie Delta. In this region large populations of broad whitefish, lake whitefish and cisco pass along the coastline, in waters of relatively low salinity, from their spawning areas in the Mackenzie Delta to their nursery and rearing areas in the streams and lakes of the Tutktoyaktuk Peninsula. Many of the fish are young of the year, juveniles and immatures. During the migration period, lasting most of the open water season, these species are at great risk from spilled oil driven ashore by on-shore winds and ocean currents. Spawning concentrations of the Pacific herring also utilize these waters.

Arctic cod, although not harvested directly by man, is the fish species of greatest significance in the Arctic marine food web. The egg and larval stages of Arctic cod occur in pelagic waters below a depth of 10 m where they would appear to be largely immune to the possible effects of oil contamination. Cod older than one year congregate in near-shore regions in the late summer when they become more vulnerable to habitat perturbation. The abundance of these near-shore aggregations fluctuates greatly from year to year, hence an oil spill that affected the population when at a low level might cause considerable local disruption in the animals and birds that depend upon them for food.

The bowhead whale, while officially an endangered species, on which there is a complete ban on harvesting in Canadian waters, is subjected, in the western Arctic, to regulated hunting by the Alaskan Inuit. In the eastern Arctic the bowhead is believed to suffer occasional illegal killings. In spite of the long-term moratorium on indiscriminate harvesting, the best information indicates that bowhead stocks are still very low compared with their numbers before the whaling era of the years 1860 - 1900. What is known of their stock structure gives cause for grave concern. There is little evidence to indicate that oil spills have any significant effect on whales. Whales have been observed 'playing' and carrying out normal activities in oil slicks without any apparent discomfort. There is a possibility that the unkeratinized skin of whales, regarded as a vital tissue, may suffer some damage when exposed to oil, but this is still conjecture. Similarly the fouling of baleen plates by oil in baleen whales might reduce feeding efficiency.

The walrus, hunted largely for its ivory at the present, is known to have suffered a great reduction in range over historic times as a result of indiscriminate hunting; it is considered to have little capacity to live sympatrically with modern man unless adequately protected. The creviced skin of the walrus may present difficulties for cleaning, and this could be compounded if walrus haul out sites were to become contaminated.

Narwhal and beluga are hunted extensively, the former for ivory as well as muktuk, the skin and subcutaneous layer of fat that is highly valued as human food. Reduction in the dog population has lessened the demand for meat and oil but ivory prices have increased rapidly in recent years. At the present time narwhal stocks seem to be maintaining themselves adequately but several stocks of beluga have been much reduced in number by excessive harvesting.

Adult seals have so far been shown to experience few after-effects from oil immersion although a number of potential hazards exist. Young pups could be affected by ingesting oil from their mothers' skin while suckling; some are believed to have been drowned through their inability to swim after becoming coated with oil. Ringed seals in captivity have been shown to develop eye infections when oil-contaminated but these effects have not been observed in oil-immersed seals in natural conditions.

The two components of the Arctic marine system most likely to suffer from oil spills are the sub-littoral fauna in water depths of 3 to 20 m, and the under-ice fauna; both are important food sources for animals higher in the food web. The mollusc beds of the benthos are probably visited by walrus and bearded seals down to a depth of 150 m, but the maximum depths utilized are not known. Productivity is probably greatest in the region below the layer of variable salinity (4-10 m) down to a depth of 50 m and it is these regions that will be most heavily utilized by the mammals. Contamination at these depths is unlikely to be great except through the formation of tar-balls: mixed oil and sand that has a density greater than water. Residual contamination of benthic molluscs is known to last for several years but should those contaminants be transferred to marine mammals living in clean water they will be readily eliminated. A major spill in winter, contaminating a large area of the substratum could conceivably have deleterious effects on bearded seals and walrus, particularly if they were prevented from leaving the contaminated area because of lack of suitable tide-cracks or polynyas in adjacent, non-contaminated areas. The length of time required for littoral faunas to return to their original condition is known to exceed ten years in temperate regions; this could be exceeded in Arctic conditions where biological processes are much slower. On the other hand true littoral faunas in the Arctic are virtually non-existent because of ice-scour; the 'submerged littoral' fauna only begins about 3 m below tide level and is therefore out of the region of greatest contamination: that above and below low and high water marks. Repeated oil spills may have very long-term, or even permanent effects.

The under-ice biota begins to develop in spring as soon as sufficient light penetrates the ice to initiate photosynthesis; the biota therefore develops to a maximum extent just before break-up and then is dispersed as the ice melts. Oil spilt on the under-surface of the ice will eliminate the biota but as encapsulation develops the fauna will reform on the new under-ice surface. In the later stages of winter, as spring approaches, rising air temperatures will preclude encapsulation, hence oil spilt at this time will remain on the under-ice surface, rendering it sterile. Whether encapsulated or not, melting in the spring will allow the oil to permeate the ice mass and come to the surface, releasing it at the ice-edge where its presence is most likely to be damaging due to the intense biological activity taking place here. Fish, birds and marine mammals all interact at this intersection of ice, air and water.

Observation and theory indicate that a highly erratic, or low total energy input to an ecosystem gives rise to a structure that is relatively simple and one in which there is considerable biomass accumulation in the terminal stages of the food chain. Primary and secondary stages may fluctuate greatly, but the system as a whole will come to a state of least fluctuation attainable. In the Arctic this implies levels of annual fluctuation in primary producers (algae, under-ice, planktonic and benthic organisms) and in secondary producers (amphipods, Arctic cod, etc.) but considerable steadiness in the terminal stages such as whales and Arctic charr.

Ecosystems adapt to an increase in the harshness of their environment (the magnitude or variability of the fluctuations they experience) by the elimination of certain species, giving rise to a reduced level of diversity; it is the large dominant or terminal species that are frequently the most susceptible to disturbance. Harshness of the environment may be increased by long-term changes in physical or chemical parameters, by an increase in harvest, or random perturbation of an intermittent nature. Elimination or reduction of the dominant Arctic species (Arctic charr, whitefish, marine mammals) will not result in any compensatory changes in other harvestable stocks, as may occur in temperate waters; neither will there be any concomitant changes in diversity that might conceivably be identified. This is because of the absence of species that might benefit. The changes most likely to occur would be an increase in the level of fluctuation in Arctic cod, a species that fluctuates greatly at the present time, and an increase in the dominance of molluscs in the benthic fauna.

Most significantly, theory indicates that numerical solutions to resource equations are not obtainable (Johnson 1981). Prediction, at best, will be in terms of scenarios, patterns and probabilities. Mathematical studies and computer simulations may assist in understanding pattern formation in the energy flow, but attempts at mathematical representation of real ecosystems may be inappropriate.

A reductionist approach to the examination of the various problems likely to be encountered may lead to the conclusion that no damage is likely to occur, indicating that it is safe to proceed with the changes envisaged. This conclusion may not be justified because of the accumulation of sub-lethal physiological or behavioural effects: essentially an accumulation of "noise" in the energy flow channels of the ecosystem.

The effect of oil on harvestable Arctic stocks, either directly or through the food chain, will be insidious. When multiple potential causes exist for a reduction in stock abundance, including the occurrence of unusual but natural environmental conditions, it will be exceedingly difficult, if not impossible, to attribute or apportion the effect of each cause separately, unless the changes are of catastrophic proportion. Effects of lesser magnitude will be time-delayed so that stock reductions will be gradual and fundamental causes inextricably mixed and irretrievable.

Growth of industrial activity as well as the human population will expose the Arctic environment to a wide variety of biological and chemical perturbations not previously experienced. Human activity will impose increased pressure on fish and mammal stocks through hunting and observation using high speed boats or aircraft. New chemical exposures may result from heat exchanger liquids, used oil, dielectric fluids, compressor gasses, fire retardants, insecticides, cleaning solvents, lubricants, plastics etc. Accidental release of such chemicals and inconsiderate behaviour may pose problems more insidious than the actual spilling of oil.

ANSWERS TO QUESTIONS

1. <u>WHAT ARE THE PROBABILITIES OF ACCIDENTAL RELEASE OF OIL AS A CONSEQUENCE OF OIL EXPLORATION, PRODUCTION OR TRANSPORTATION IN ARCTIC WATERS? GIVE SEPARATE CONSIDERATION TO RELEASE IN OPEN WATER, IN POLYNYAS, UNDER SHORE-FAST ICE OR UNDER PACK ICE.</u>

In general, offshore oil operations have given rise to frequent small spills, but it is the infrequent big spill that accounts for most of the oil released.

Approximately 6 million tonnes, 30 million bbls (barrels), of oil are released annually into the marine environment. Of this annual input to the oceans about 35 percent comes from marine transportation generally, of which only about 3 percent originates from tanker accidents; 26 percent comes from river run-off with smaller contributions from coastal refineries, municipal wastes and the atmosphere (Wilson and Hunt 1975). Oil input to the oceans from offshore drilling operations amounts to 1.6 percent of all spillage (480,000 bbl) but this estimate was made prior to the massive blowout in the Gulf of Mexico from IXTOC 1, or more recently the one in the Persian Gulf.

Of the number of blowouts recorded, 40 percent occurred during exploration drilling and 60 percent during production drilling; the amount of oil spilled, generally, is greater from production blowouts. Blowouts during production operations are mostly due to accidents such as the collision of a vessel with the platform, fires on the platform, platform failure or failure of other components. For an oil field of over 2 billion barrels, over its 20-year lifetime, there is a 70 percent chance of an incident that will result in the discharge of more than 1000 bbls. For a field in the size range 500 million to 2 billion bbls, the probability is 25 percent. A spill of 1000 bbls is generally considered by the industry to be a relatively minor affair (Dexter 1981).

More than 60 percent of recorded blowouts are bridged, that is to say, plug themselves by collapse under the flowing forces from the oil bearing strata, within a few days. If bridging is going to occur it usually does so within 5-20 days of the commencement of the blowout. In the North Sea, blowout spills of over 1000 bbls averaged less than 2 per 1000 wells drilled; latest figures indicate that over 1600 additional wells have been drilled without further blowout spillage. On the Outer Continental Shelf of the United States 46 blowouts occurred in the period 1971-1978: thirty of these occurred during drilling operations and the remaining 16 during completion, production and workover operations. During this period 7553 new wells were started; one blowout occurred for every 250 wells drilled. This appears to be a high proportion but the American statistics list all spills over 1 bbl. Oil and condensate production over this period amounted to 2.8 billion bbls with the total blowout spillage being less than 1000 bbl. Shortly after the period under discussion the major blowout at IXTOC 1 occurred in the Mexican sector spilling over 3 million bbls (600,000 tons) into the ocean (Dexter 1981).

Off the Canadian East Coast 172 wells have been drilled without mishap.

Spills of up to 1.5 million bbls are considered possible in the Arctic (Milne 1979).

In addition to blowouts a major release of oil into the ocean may arise from projected failure or breakdown in one of three major areas: a) failure of drilling platform during extraction operations; b) holing or wreck of tanker during delivery, and c) failure of a subsea pipeline during collection or delivery. Each of these features will have a different risk factor associated with it and the total magnitude of the risk will depend on the extent to which platforms, tankers or pipelines are employed. The total risk is therefore dependent on engineering and operational decisions that will have to be made with respect to the production and delivery systems employed, i.e. platforms vs artificial islands and tankers vs pipelines.

The greatest hazard to drill platforms and drillships arises from weather and oceanographic conditions: the association of storms, high waves and ice. The probability of such events may be determined, but the engineering to meet all eventualities does not yet appear to be developed. It must also be recognized that the variances associated with meteorological events increase with time (e.g. the 50 yr, 100 yr, 1000 yr flood): the 1000-yr event may occur tomorrow, not necessarily in 1000 yr. Lack of oceanographic and meteorological data over long time periods makes prediction of events in the Arctic particularly difficult.

Most tanker accidents occur as a result of navigational hazards associated with human error and equipment failure. These hazards can be reduced by improved navigational surveillance and operational control and continual attention to improved tanker designs for ice-navigation.

Techniques for overcoming the difficulties associated with Arctic conditions are still in their developmental stages. If production develops then operations will gradually increase. Every effort should be made to obtain maximum information through suitable investigations and monitoring procedures in order to improve operational techniques and reduce risks.

For fields using subsea gathering pipelines and tankers, spills could amount to about 0.01 percent of oil produced offshore. This compares with an estimated 0.005 percent for equivalent land-based pipeline connected fields (Milne 1979).

The presence of ice and the extreme working conditions in the Beaufort Sea add another dimension to the probability of accident. Whilst comparable in rigour with drilling off Newfoundland in Northwest Atlantic waters, the hazards are of a very different nature. The use of artificial islands in the Beaufort Sea reduces the risk of subsea blowouts, making operations in this phase more comparable with those that are land-based. To date, two blowouts, involving only water, not oil, have been recorded in the Beaufort Sea operations.

In high energy environments where there is rapid dissipation of wind or wave energy, oil is dispersed rapidly. The open ocean of temperate and tropical regions is a high energy environment, except in periods of complete calm, so that dispersal is usually quite rapid leaving little observable detrimental effect. The Arctic Ocean however presents very different problems. The geographical location of the present wells, the routes that would have to be taken by tankers, and the prevailing oceanographic conditions, virtually ensure that the oil from any spill of consequence will be washed ashore. Given average wind speeds of 20 km h^{-1} in the Beaufort Sea, a drift rate of 14 km day^{-1} can be anticipated. Storm surges along the flat shorelines of the south coast of the Beaufort Sea, both negative and positive, of up to 1 m above or below normal water level (Milne and Herlinveaux 1973), could expose large areas of land or subtidal sediment to oil contamination.

Oil spilled under shore-fast ice is likely to arise either from a blowout or pipeline rupture. The most likely cause for pipeline rupture would be the onshore drift of large icebergs or multi-year ice accumulations whose keel depths greatly exceed normal expectation (i.e. for engineering design). Evidence of iceberg scour has been found at depths down to 45 m.

Oil and gas from a blowout rise in a plume to the undersurface of the ice where they spread out laterally; surface tension effects lead to the formation of globules that create a layer at least 8.0 mm in thickness; this limits the effect of spreading. Currents in excess of 30 cm sec^{-1} are believed to be necessary to move oil under the ice. The buoyancy of the gas will cause the ice to fracture, allowing the gas to escape and the oil to reach the upper surface of the ice, with the oil then spreading out over the ice surface. In areas where there is no vent to the atmosphere, oil will accumulate in cracks and fissures of the under-ice surface. Spreading will be prevented by the formation of a lip of ice around the periphery of the "moon pool" on the under-surface of the ice owing to the differential thermal properties of oil and ice, as well as the irregularities of the under-ice surface.

In spring the oil will move upward through cracks and brine fissures as the ice begins to melt and fracture, until it emerges on the surface. The greater heat absorption properties of the oil will cause the contaminated area to melt one to three weeks before the general failure of the ice in the surrounding sea. In multi-year ice the encapsulated oil may travel for a number of years before being released. Oil released on the surface in spring after being encapsulated over winter was burned off with some degree of success, following an experimental spill under shore-fast ice in a comparatively enclosed bay (Milne 1979).

Oil spilled in pack ice will accumulate on the surface of the water in the leads between the floes. In windy conditions, and depending on floe-size, the water between floes will represent a relatively high energy environment and hence dispersal will be relatively rapid.

Oil spilled in polynyas will tend to be confined if the polynyas are comparatively small; however, polynyas are frequently areas of water upwelling and surface movement; they therefore provide a high energy water-ice-air interface that will tend to facilitate dispersal.

2. <u>WHAT CONCENTRATIONS OF OIL FRACTIONS MIGHT BE EXPECTED TO OCCUR IN OPEN WATER, UNDER ICE, IN THE PLANKTON AND IN THE BENTHOS AS A RESULT OF SUCH RELEASES AND WHAT WOULD BE THE EXPECTED RATE OF CHANGE IN THESE CONCENTRATIONS?</u>

Levels of oil contamination that can be expected in the water column following a spill will depend on a) the seastate; b) water column depths, and c) the dispersion in the water column.

Short-term total hydrocarbon concentrations that may be expected in the water column are in the range of 10 to 200 ppb with an upper maximum of 300 ppb. These concentrations are for the upper 10 metres with a range of 10-25 ppb for deeper waters; such concentrations will be relatively short-lived particularly in open oceans or in storm conditions. There is a high degree of toxicity associated with newly dispersed oil due to the presence of the more toxic, lower molecular weight hydrocarbons. In the open ocean these are generally lost to the atmosphere through evaporation within 24 to 48 hours (Vandermeulen 1981). In ice-covered waters mixing and dispersal will be reduced and evaporation will be largely eliminated resulting in prolongation of the time during which toxic conditions exist.

Oil spills may result in hydrocarbon concentrations of 10-100 ppm in bottom sediments, depending on the depth and degree of mixing in the water column. Sediment-bound hydrocarbons are highly persistent and may remain detectable for up to 10 years.

Below 50 ppm there appears to be some stimulation of phytoplankton production by dissolved hydrocarbons but effects on phytoplankton have been measured at concentrations as low as 100 ppb.

Oiling of zooplankton was observed following the spill of the Argo Merchant 29 miles southeast of Nantucket Island, Massachusetts. The range of hydrocarbon concentration was from 0.24 to 117 ppb. No physiological perturbation or massive mortality was observed. Macrobenthos appeared to escape impact in this spill (Vandermeulen 1981).

In the Amoco Cadiz disaster off the coast of Brittany vast mortalities occurred among benthic organisms, including various species of bivalve and heart-urchin. This was attributed to high turbulence and rapid mixing in the water column, bringing lower molecular weight hydrocarbons into contact with benthic organisms before the hydrocarbons had had time to evaporate. Fish eggs and larvae also suffered considerable mortality in this event.

In test spills at Balaena Bay near Cape Parry, Adams (1975) found that primary productivity measured by ^{14}C uptake was slightly enhanced in the vicinity of oil, in spite of lower light intensities in the oil shadow. Following the burning-off of the oil reaching the surface in spring, dense masses of normally benthic blue-green and macrophytic algae developed on the ice surface.

There is accumulating evidence that significant changes in diversity have occurred in the benthos in the proximity of oil rigs in the North Sea, but the work is still in its early stages. In Chedabucto Bay, Nova Scotia, soft-shelled clams, <u>Mya arenaria</u>, were found to have hydrocarbon levels in excess of 200 ppb six years after the spill; however no effect on the organisms was indicated (Gilfillan and Vandermeulen 1978).

Shorelines are usually the regions most seriously damaged by oil spills. At Balaena Bay the shingle on shore was contaminated with a light surface film of relatively insignificant proportions. No effect on benthos or other parts of the marine ecosystem was observed. Small salt marshes in the region were believed to be the most vulnerable part of the system with respect to oil contamination.

In the BIOS experimental oil spill program at Cape Hatt, northern Baffin Island, investigations showed that ice-scour during winter stripped the shoreline clean of oil, redistributing sediments down to a depth of 3 m.

Biodegradation, in the Arctic, studied extensively in the BIOS program at Cape Hatt, appears to be very limited in extent. For example, Bunch et al. (1981) state that "Oleoclastic bacteria capable of hexadecane mineralization were inactive or not present in the sediment in detectable numbers." This is confirmed by Boehm (1981) who states that "the first year of oil weathering studies from the Lagoon and Eclipse Bay shorelines indicated a small degree of weathering and dilution occurs shortly (1 day) after the application, but only minimal (but measurable) weathering proceeds further during the first 16 days. No indication of biodegradation was noted, probably due to the very high oil levels versus available nutrients".

3. WHAT WOULD BE THE PHYSIOLOGICAL AND ECOLOGICAL CONSEQUENCES OF SUCH OIL CONCENTRATIONS FOR FISH AND MARINE MAMMALS THAT WERE IN THE AREA AT THE TIME?

The species most at risk are the coregonid stocks using the Beaufort Sea coastal waters during the open water season, and the Pacific herring stocks that utilize the shallow waters, particularly in the Liverpool Bay region, for spawning in the early spring. The coregonid stocks include representatives of most age classes in the immature segment of the population; loss of this segment, or a significant portion of it, could have serious consequences on the harvestable and spawning stocks. The loss of a single season's spawning in the Pacific herring, would doubtless be a matter of grave concern, but even such a tragedy would be unlikely to be identifiable by the time the missing year class would have come to first maturity.

The effect on the two most widespread fish species in the Arctic system, Arctic charr, Salvelinus alpinus, and Arctic cod, Boreogadus saida, is likely to be negligible. No effect on marine mammals at observed concentrations has been demonstrated (Geraci and Smith 1976, 1977).

The most vulnerable stages in fish occur early in the life history following hatching. In Arctic charr, eggs are laid and the young hatch in freshwater; the juveniles remain in freshwater until 4-8 years old and a size of 150-220 mm; only at this time do they enter the marine environment. The spawning grounds of Arctic cod in the Canadian Arctic have not been located but eggs and newly hatched fry have been caught in many areas. Fry are found in pelagic waters usually at depths below 10 m; only when they are at least one year old do they move inshore.

The most likely effects on these fish species is the possible poisoning of the sub-tidal fauna (3-20 m) on which both species depend. Other fish species such as Gymnocanthus spp. and Myoxocephalus spp. are restricted to the subtidal zone and are more likely to be affected; the effect of contamination on these species is still under investigation at the BIOS experimental site at Cape Hatt.

The marine mammal at greatest risk is the ringed seal, Phoca hispida, particularly during the pupping period in spring (April-May) and the moult period of the adults in May-June (Table 1). The pup is born with a white 'lanugo' coat that would probably lose its insulative capacity if fouled with oil. However, as shown by the Antarctic Weddell seal, Leptonychotes weddelli, the adult thermoregulatory capacity is established within 9 days of birth. Once this occurrs the vulnerability to oil contamination of the coat will gradually diminish until the time the pup leaves the lair some two months later having assumed the pelage fully adapted to the marine habitat.

If an oil spill occurs in winter under the fast ice occupied by ringed seals, it seem inevitable that oil will tend to reach the surface through the breathing holes; the holes, in fact, will become plugged with a column of oil two to three metres long. The ability of seals to move out of such areas and create a new network of breathing holes will be severely restricted, as most suitable areas are occupied, and other seals, being territorial, would strongly resent the intrusion of newcomers.

Table 1. Estimated sensitivity of individual adult marine mammals to an oil-environment under various ice conditions.

	Open water	Polynya	Pack Ice	Fast Ice
Harp	1	-	-	-
Hood	1	-	1	-
Ringed	1	2	2	3
Bearded	1	2	2	-
Walrus	1	2	2	-
Beluga	1	2	2	-
Narwhal	1	-	2	-
Bowhead	2	-	2	-

Rating: 1 - unlikely to be harmful
2 - possibly harmful
3 - probably harmful

Note: Seals are likely to be harmed if they are prevented from moving out of the territory that they inhabit. This would frequently be the case since all other suitable territories would be already occupied. The white-coated young of seals are more likely to be vulnerable than adults. No effects of oil on whales has been demonstrated but, because their skin is an unkeratinized vital tissue, damage is likely.

It is probable that similar constraints apply to the young of bearded seals in the presence of oil, but little is known on specific points. It seems probable that bearded seals would be able to move away from contaminated areas more readily than ringed seals as they are not so tied to a territorial system of breathing holes.

Polynyas, tide-cracks and leads will similarly be areas in which oil will be confined if a spill or blowout occurs on the sea bottom. These openings in the ice are frequently areas of high usage by marine mammals, particularly those that have difficulty in maintaining their own breathing holes such as bearded seal and walrus, and young ringed seals. It, therefore, seems highly desirable that the contamination of such areas should be avoided.

The bowhead whale feeds principally by skimming the surface waters. There appears to be some danger that oil might be taken in and clog the baleen plates used for filtering the planktonic food. The calving areas of this species are not known, but again, it seems most likely that the neonates would be most vulnerable to contact with oil. In winter the bowhead spends its time in the fringe areas of the pack ice where ice cover is somewhat less than 50 percent; these are high energy environments and oil dispersal is likely to be rapid.

The narwhal is known to calve only in the deep waters of the fiords of northern Baffin Island. It therefore seems most important to avoid any possible oil contamination in this area during the open water period. In late winter narwhal have been found in areas of pack ice with an ice-cover of between 90-99 percent. These again are likely to be high energy environments in which the oil is quite rapidly dispersed.

The view, held until quite recently, that beluga enter the warm waters of estuaries to calve (particularly the Mackenzie Delta and the estuaries of the Churchill and Nelson rivers flowing into Hudson Bay, and, although not an estuary, Cunningham Inlet, Somerset Island), has now been modified as many animals have been seen entering these waters with young already at their side. This species is likely to be most vulnerable at this time on account of the presence of very young animals in confined circumstances. The exact effects can not be specified. In late winter, the beluga, as with the bowhead, is found on the fringes of the pack in waters with up to 50 percent cover.

In cold waters floating oil may become emulsified with water and air forming "chocolate mousse". This may be converted to a form denser than water with the addition of sediments filtered out of suspension. This mass of oil and sediment then sinks to the bottom covering and smothering the benthos. In a more weathered form "tar-balls" may develop which have the capacity to move across the sea-bed until brought to rest by irregularities in the substratum.

A larger spill of heavy crude oil could conceivably cause considerable damage to the benthic fauna, particularly the clam and mussel beds on which the walrus and bearded seal depend to a large extent. It has been shown that clams can retain detectable traces of hydrocarbons for up to six years following contamination. There is no report of any lethal or sub-lethal effect from these concentrations and it is most unlikely that they would cause significant impairment at higher levels in the food chain, in either the walrus or bearded seal. Ringed seals showed no irreversible effect after ingesting 5 mL of Norman Wells crude each day for 5 days.

The greatest ecological danger appears to be the effect of oil on the sub-tidal flora and fauna and the under-ice biota. These are probably the two most productive systems in the Arctic marine environment.

In most cases it has been shown that intertidal regions are the most seriously damaged parts of the ecosystem. Rocky shore communities in temperate regions have taken over 10 years to recover completely, while salt marshes may take up to 20 years to return to their former state. However, in the Arctic, intertidal biota is almost non-existent owing to intensive ice-scour; fine sediments tend to be redistributed leaving mostly coarse particles in the littoral region. Salt marshes are infrequent and only occur in very sheltered areas.

4. WHICH STOCKS OF FISH AND MARINE MAMMALS ARE VULNERABLE TO OIL SPILLS IN THE ARCTIC? WHICH STOCKS ARE ESPECIALLY SENSITIVE FOR ONE OR MORE OF THE FOLLOWING REASONS: i) THEY ARE HEAVILY EXPLOITED; ii) AT SOME STAGE IN THEIR LIFE HISTORY THEY OCCUPY CRITICAL HABITATS, E.G. BREEDING GROUNDS OR FEEDING GROUNDS THAT MIGHT BE IMPACTED BY OIL, AND iii) THE SPECIES EXHIBITS SOME CRITICAL PHYSIOLOGICAL OR BEHAVIOURAL SENSITIVITY TO OIL?

In general, stocks that aggregate will be more vulnerable to any local perturbation, should they encounter it, than those that are widely dispersed. Stocks with long recovery times will be more severely affected than those with rapid turnover times. Sensitivity to oil will not be increased at a time of low stock density but the ecological effect of an additional perturbation may be much greater than when densities are higher,in that it will tend to increase the time to recovery. Minor chronic perturbation may maintain a stock at low density indefinitely.

Arctic charr tend to aggregate during their summer feeding migration to the sea. However, their pattern of distribution is widespread and in many areas considerable interchange of stocks takes place. Severely depleted charr stocks have been shown to recover given sufficient time. Disruption of the sub-tidal zone, the principal feeding area of the charr in the sea, could create a temporary set-back, but charr normally experience a high degree of annual variation in summer food availability. Contamination of the flesh, rendering it unpalatable, is a most probable effect. Stock density seems to have little effect on feeding pattern as reflected in size and growth rates. Little can be said about Arctic cod as the stocks show very great variability in both time and space. Stocks of whitefish and cisco, in the Mackenzie

Delta and along the southern coast of the Beaufort Sea will be most vulnerable to the onshore drift of oil. These stocks are exploited to the limit particularly in the Delta region.

As noted in the answer to Question 3, the mammal species most likely to be directly affected by oil contamination are ringed and bearded seals during pupping and moulting, and the bowhead during feeding. Ringed seals, on account of their very wide distribution, will only be affected locally and recovery is likely to be quite rapid when the perturbation ceases. Bearded seals are also widely scattered across the Arctic; although less abundant than ringed seals they tend to be more highly aggregated. It appears that they are not, on these counts, likely to be at any greater risk of disruption.

The bowhead whale and walrus are both species whose numbers have been greatly reduced over historic times; in addition the range of the walrus has been severely reduced. If both species are to be preserved great care must be exercised to eliminate chronic perturbation of all types. Bowhead stocks are at a much reduced level and in the western herd a very high ratio of juveniles to adults gives cause for grave concern. Continued aboriginal hunting may be arresting the recovery of this species in the Western Arctic, and illegal shooting and other unknown perturbations continue to keep the Eastern Arctic population at a very low level.

Hunting pressure on the walrus at the present time is probably less than formerly, as the need for dog food and harpoon lines has been reduced by the importation of snowmobiles and nylon rope. Hunting, however, is beginning to increase again as the value of ivory obtained from the tusks increases. The levels of exploitation relative to the total stock are exceedingly difficult to obtain because of movement and migration patterns and widespread distribution. Walruses depend on haul-out sites on land (uglit) in summer and on strong pack-ice in winter. The effect of oil contamination of such sites is not known but conceivably could be deleterious, particularly from March to May when the young are born.

The migration pattern of whales is reasonably well documented. In the Western Arctic, beluga and bowheads move northeast across the Beaufort Sea in heavy pack ice in early spring, utilizing a system of leads that develops far offshore between Point Barrow and northern Banks Island; they then pass southward along the west coast of Banks Island finally arriving in the large polynya in the Amundsen Gulf one or two months before general break-up of the ice in June-July. From here they make their way, in open water, to the Mackenzie Delta; they then retire in October-November to the pack ice of the Bering Sea to overwinter. This migration route is quite well defined but the migration takes place over an extended time period as animals do not move in large groups (Fraker 1979).

In the Eastern Arctic there is a regular movement of bowheads, narwhal and beluga from the pack ice of Davis Strait and Baffin Bay into Lancaster and Jones Sounds, and even into areas further north. In the more southerly regions, animals overwintering in the Hudson Strait pack move into Hudson Bay and Foxe Basin with beluga also moving into Ungava Bay and Cumberland Sound. These movements appear to be somewhat irregular both in timing and in the routes actually taken, making it difficult to specify times or places that should be avoided by drilling rigs or tanker traffic.

It is known that four local stocks of beluga are currently being harvested above a sustainable level (East Hudson Bay, Ungava Bay, Cumberland Sound and St. Lawrence Estuary) (Finley et al. 1981). Severely restricted harvesting, or preferably a complete moratorium on harvesting for some years, will be necessary if these stocks are to regain abundances that permit limited exploitation.

Areas of concern with respect to aggregation of stocks are: Nelson and Churchill river estuaries (beluga); Cumberland Sound (beluga, bowhead); Cunningham Inlet (beluga); Lancaster Sound (bowhead, beluga, narwhal, walrus, seal); Jones Sound (walrus); eastern Hudson Bay (beluga); Ungava Bay (beluga); Hudson Strait, Southhampton Island and Foxe Basin (walrus); Creswell Bay (narwhal, beluga); Amundsen Gulf (bowhead, beluga); and the Mackenzie Delta and southern Beaufort Sea (bowhead, beluga and whitefish).

Areas of a more general nature that are of great importance in the energy flow through Arctic ecosystems are: a) the under-surface of the ice particularly in the spring (April-May-June) before breakup when activity of the under-ice biota is greatest; b) the ice-edges that form in spring during breakup and are frequently the site of great biological activity involving Arctic cod, marine mammals and sea birds, and c) the inshore sub-tidal zone about which relatively little is known.

The only critical stages in the life history of marine mammals that can be recognized are the periods of pupping and moulting in seals and the period of calving in whales. Apart from the ringed seal (the species that has been investigated in greatest detail), the information available is very meagre and does not support any generalizations.

The larval stages of fish are those most vulnerable to contaminants. In Arctic charr and all whitefish species larval stages occur in freshwater and therefore are outside the discussion; larval stages of Arctic cod occur in deeper waters (10-120 m), largely below the zone of significant contamination. Larval stages of littoral fish species are the ones most likely to be affected.

5. WHICH STOCKS SHOULD D.F.O. SEEK TO PROTECT BY REQUESTING PARTICULAR AREAS OR TYPES OF HABITAT (E.G. POLYNYAS, AREAS OF PERMANENT SHORE-FAST ICE) BE PROTECTED FROM OIL-RELATED ACTIVITIES?

There is general consensus that evidence for the effect of oil on fish and marine mammals is of a rather tenuous nature, making it difficult to establish the particular times of the year when particular regions should be protected.

Animals that congregate to any appreciable extent are more vulnerable to any form of perturbation that affects them during their period of aggregation than are those that are more uniformly distributed. The area of greatest aggregation of marine mammals and birds is, unquestionably, Lancaster Sound. The reasons for this concentration of biological activity are inadequately known and understood.

In addition to Lancaster Sound the following localities need protection from perturbation, at least during the periods of the year when they are being utilized by the pertinent stocks:

Beluga	Bowhead Whale
Nelson River Estuary	Hudson Strait
Churchill River Estuary	East Coast of Greenland
Cumberland Sound	Roes Welcome Sound
Cunningham Inlet	Southern Beaufort Sea
Creswell Bay	Mackenzie Bay
Amundsen Gulf	Amundsen Gulf
Mackenzie Bay	
Southern Beaufort Sea	
Eastern Hudson Bay	**Narwhal**
Ungava Bay	Northern Baffin Island Bays
	Creswell Bay
Walrus	
Jones Sound	
Hudson Strait	**Whitefish**
Southampton Island	Southern Coast of Beaufort Sea
Foxe Basin	Mackenzie Delta
Cumberland Sound	

Arctic charr occupy most inshore regions in the Arctic in summer particularly the less exposed shorelines of bays and estuaries; whitefish are concentrated in the coastal waters of the Beaufort Sea.

Polynyas are areas of aggregation of marine mammals in winter (they are also of particular importance to birds in early spring). The local nature of polynyas and the consequent lack of alternative breathing sites, may prevent the migration of animals into oil-free water.

Shore-fast ice occurs throughout much of the Northwest Passage, the projected tanker route. This, as pointed out above (Question 3), is occupied by adult ringed seals in winter, and in spring by pupping and moulting animals.

6. WHAT KINDS OF OBSERVATIONAL PROGRAMS WOULD BE REQUIRED TO DETECT: i) DELETERIOUS EFFECTS ON MARINE FISH OR MAMMAL STOCKS, AND ii) THE RECOVERY OF THE ECOSYSTEM FROM THE EFFECTS OF AN OIL SPILL?

i) It is generally conceded that it is virtually impossible to detect the effect of an oil spill in marine conditions unless it is of catastrophic proportions. This is particularly the case with respect to fish and marine mammal stocks where the effect on recruitment may only be apparent after a time-lag of several years. This being so for the highly studied east coast of Canada, it is even more difficult to expect valid statistical evaluation in the Arctic where, not only is the biology of the system incompletely known, but the great difficulties of enumerating stocks are frequently compounded by high natural fluctuations in abundance and migration pattern. The wide distribution and poorly known behaviour of most Arctic marine mammals makes it exceptionally difficult to quantify the stocks. Even more difficult is the problem of obtaining representative biological samples for the determination of age (compounded by the difficulties inherent in the aging process itself) and reproductive cycle; for bowheads, samples are impossible to obtain in Canada as all hunting is banned. Great difficulties also present themselves when attempting to quantify energy flow through the Arctic ecosystem, but unless we have some appreciation of these parameters most attempts to estimate sustainable yields will be largely informed guesses.

The immediate need is undoubtedly for good, long-term, basic oceanographic and biological studies directed towards the processes involved in the formation and characterization of Arctic ecosystems. Only with a good understanding of the mechanisms involved can effective corrective or preventive measures be formulated.

Studies on the energetics and population dynamics of the Beaufort Sea coregonids and the biota of the under-ice surface and sub-tidal regions as well as the oceanographic conditions and biological oceanography of such characteristically Arctic features as polynyas and 'ice-edges' are of vital importance in understanding Arctic ecosystems.

Another approach, and undoubtedly one of increasing importance, is through experimental programs, directly testing hypotheses and carrying out observations under controlled or at least confined conditions. Such programs as those at Balaena Bay (Beaufort Sea Project) and Cape Hatt (BIOS Program) should be encouraged and expanded, as well as physiological studies on fish and the smaller marine mammal species. Pinnipeds have been successfully maintained experimentally but small whales are more difficult to keep under similar conditions: with the bowhead whale it is virtually impossible.

ii) Experimental studies on ecosystems appear to be the only way of gaining insight into the processes of damage and recovery following an oil spill. Long-term observations on uncontaminated systems are essential to establish 'base-line' conditions. In the event of a major oil spill it seems impossible to determine when recovery will have been effected unless good information on the pre-perturbation state is available.

7. WHAT KINDS OF PREVENTIVE MEASURES OR COUNTERMEASURES WOULD BE APPROPRIATE IN RESPECT OF: i) CHRONIC LOW-LEVEL POLLUTION, ii) MAJOR SPILLS, OR iii) BLOWOUTS? IN THE EVENT OF A MAJOR SPILL OR BLOWOUT, SHOULD

D.F.O. SEEK TO HALT OIL OPERATIONS IN THE AREA UNTIL THE SYSTEM HAS FULLY RECOVERED? IF NOT WHAT ACTION IS CALLED FOR?

"An ounce of prevention is worth a pound of cure", and "more research into preventive measures is essential" are the two main statements that can be made, even if rather trite. Many of the concepts and much of the equipment to be used in the Arctic in oil exploration, extraction and delivery systems will be initially untried under operational conditions. It is therefore important that full precautions be taken at all times with observations on performance and potential weaknesses carefully documented.

Preparation for containment of an oil spill should be made well in advance of an incident, and necessary materials and equipment should be readily available. Consideration should be given to the postponement of the start of production until satisfactory clean-up procedures have been developed.

i) In the event of a spill the causes should be fully investigated in open hearings in order to prevent re-occurrence.

The prevention of chronic spills is a matter of good housekeeping, which involves the continuous maintenance of good equipment, alertness and a sense of personal responsibility. These factors can be improved through good training programs for personnel at all levels.

This approach should be encouraged by:

a) education in environmental matters;
b) punishment for human frailty, and
c) suspension of permit for non-compliance.

ii) Similarly acute spills can be reduced by care and improved engineering techniques. Improved vessel design is essential and double hulls with dual propulsion and steering systems should be mandatory for ice-breaking tankers; adequate navigational aids must be provided and ice-breaker assistance should be available when required.

In the event of a spill, clean-up methods should be largely physical; innovative clean-up methods for physically bringing the oil to the surface for burning should be investigated.

Initially the use of chemical dispersants generally proved to be more detrimental to the environment than the effect of oil itself. Newer dispersants are reputed to be less toxic and to have a less adverse effect on physical characteristics of the oil (i.e. they do not cause deposition of oil-dispersant-water emulsions on bottom sediments).

Dispersants should be used only for the protection of specific sites when other methods fail or are inapplicable, e.g. protection of bird loafing or feeding areas.

iii) The prevention of blowouts is 99 percent care and engineering but it seems that total prevention is virtually impossible given present techniques; individual variables in each well create a very wide spectrum of possibilities. There is always the chance of an IXTOC 1 or an Ekofisk disaster. Undoubtedly the chances of such an occurrence can be reduced by improved engineering and experience.

It seems scarcely feasible or practical to halt operations until the ecosystem has "fully recovered". "Full recovery" is not a good procedural concept. This description would involve judgement and could be the basis of much bitter controversy. However operations in the neighbourhood should be halted until the cause of the accident has been established and remedial measures instituted to prevent its re-occurrence. Only when the spill has been "cleaned-up" should operations be resumed. "Cleaned-up" is also a poor operational standard but it could be defined for any particular locality.

CONCLUDING STATEMENT

Throughout the proceedings, discussions and reviews that have given rise to this document constant pressure has been applied to the Working Group to make it more concise and more definitive and, where facts run out, to attempt definitive judgements based on the best information available. Ultimately judgments have to be made in the preparation of environmental control legislation; it is therefore reasonable to expect that those more intimately concerned at the scientific level should make the primary scientific judgments.

With the best will in the world such judgments evade our capacity to make. We resort to the Socratic approach of examining the nature of the 'good' and the involuted processes that govern the actions of the 'good man'. Socrates' only claim to wisdom is that he knows nothing; it is the examination that is important, as he states "it is the unexamined life that is worth nothing". It is the continuing scrutiny, discussion and modification that is most important.

As part of such an examination a reductionist approach is essential to determine what is known of specific relationships between animals and plants and their environment and the effect of environmental change upon them. At this level, when considering the effect of oil on fish and marine mammals in the Arctic, it is difficult not to agree with the British Royal Commission on marine pollution, that there is little evidence for the impairment of the ecosystems of the high seas through oil contamination. The case for impairment of salt marshes, littoral and sublittoral systems is more conclusive and recovery periods of 10 to 20 yr have been determined. The effect of oil on marine birds is disastrous as it is on those marine mammals relying on fur for insulation. The damage to amenities and aesthetics from an oil spill is incontestable but usually temporary.

However, biologists who have been intimately concerned with the problems of oil contamination and the recovery of oiled habitats express great unease about long-term effects and repeated perturbation (Sanders 1978; Sanders et al. 1980; Southward 1981; Southward and Southward 1978).

The alternative to a reductionist point of view is a more holistic approach, and here, if the summing up is adverse, it is easy to stand accused of expressing prejudice, dislike or even moral indignation as a substitute for reasoned argument. The holistic approach may indeed provide cover for such a retreat but it does not eliminate the reality of the fact that systems are not fully understood through reductionism. Watt (1947) one of the founders of modern ecology made this very plain:

> ". . . . . clearly it is one thing to study the plant community and assess the effects of factors which obviously and directly influence it, and another to study the interrelations of all components of the ecosystem with an equal equipment in all branches of knowledge concerned. With a limited objective, whether it be climate, soils, animals or plants (populations) which are elevated into the central prejudiced position, much of interest and importance to the subordinate studies and . . . to the central study itself is set aside. To have the ultimate, even if idealistic, objective of fusing the shattered fragments into the original unity is of great scientific and practical importance; practical because so many problems in nature are problems of the ecosystem rather than of soil, animals or plants (populations) and scientific because it is our primary business to understand . . . (As) T.S. Elliot said of Shakespeare's work: we must know all of it in order to know any of it."

We therefore need a reductionist approach but recombination of the various pieces examined does not provide an adequate picture of the whole. Where whole ecosystems have been examined experimentally, the results have frequently been surprising, or out of line with initial predictions or assumptions.

One of the most difficult aspects of the degradation of ecosystems to combat is 'destruction by small increment' (Livingston 1981a), each increment in itself being relatively harmless and of little consequence but cumulatively spelling disaster. This feature has also been expressed in economics as 'the tyranny of small decisions' (Kahn 1966; Odum 1982). Ecologically this may be developed more fully under the heading of an increase in environmental "noise" or an increase in random environmental variability. In other words not only do we have to examine the nature of the imposed environmental changes, we also need to know their pattern of occurrence and range of variability. The effect of change on a reference species will differ according to the animals and plants with which it is associated. Such matters can not be investigated in isolation.

There is little doubt that there is an inherent tendency in man, whether he be modern and western or ancient and less sophisticated, to reduce the number of species with which he comes into contact (Diamond 1982). In this process of attrition the first animals to be eliminated are usually the large or flightless. This trend is readily visible in the Arctic where the largest animal, the bowhead, is certainly the one at greatest risk. Frequently the cause is attributed to excessive hunting but inadvertent habitat modification may also be a factor of importance.

The definitive answer to the question "Will oil affect Arctic marine fish and marine mammals?" is an unqualified "yes". The supplementary question "By how much?" can only be answered by the degree and type of control that is imposed on the exploration, extraction and delivery of the oil, the magnitude of the operation at its maximum, and the degree of personal responsibility that is assumed by all individuals concerned.

Protection of the environment and the stocks supported lies in the imposition of strictures and prohibitions based on judgement backed up by theory and extensive knowledge.

Regulatory regimes should be cautious, reflecting the level of uncertainty with which effects can be predicted. Regulations should also reflect a 'design' approach, the achievement of long-term goals through the establishment of suitable criteria to govern all operations, rather than a 'planning' approach which implies active management (Ophuls 1977 p. 228).

RECOMMENDATIONS FOR FURTHER STUDY

1. The most pressing need is the development of a sound theoretical and philosophical base capable of generating new ideas and conclusions and the testing of these outputs by:
   i) The promotion of studies in non-equilibrium thermodynamics and statistical mechanics as applied to ecological problems. Recognizing that numerical solutions to specific ecological problems are most unlikely to be obtained, the objective should be to examine the development of ecological patterns under changing environmental conditions.
   ii) The promotion of experimental work on natural ecosystems with the specific objectives of: a) investigating energy pathways, b) the recovery of systems following perturbation.
   iii) The development of an environmental ethic and sound philosophy of environmental affairs by the promotion of discussion and interaction with philosophers and economists specializing in environmental matters (e.g. Ophuls 1977; Livingston 1981a,b).
2. The establishment of long-term monitoring sites to observe natural fluctuations in biological and oceanographic parameters.
3. Long-term studies on biological processes in the Arctic, particularly: a) the oceanographic origin of ice-edges and polynyas; b) the origin of the biological activity at

ice-edges and polynyas; c) studies on the under-ice biota, and d) studies on the interaction between fish and birds.

4. Experimental studies on the interaction between oil, dispersants, sea water and ice, and the toxicology of the resulting conditions. New chemical exposures may result from heat exchanger fluids, used oil, waste drilling fluids, dialectric fluids, compressor gases, fire retardants, insecticides, cleaning solvents, lubricants, plastics etc. Accidental release of such chemicals may pose a threat more insidious than the actual spilling of oil.

5. Studies on the life-history, population fluctuations and role within the ecosystem, of Arctic cod.

6. Studies on the distribution, migration behaviour, acoustic responses and reproduction of sea mammals.

7. The enumeration of sensitive areas and the categorization of their biological characteristics. This should include a detailed study of the biology of the Mackenzie Delta and Lancaster Sound.

8. It is possible that sub-lethal effects may be identified by the investigation of enzyme systems. Animal responses to oils include changes in certain enzyme levels; measurement of these levels may offer a means of determining whether animals are responding to oils or something else, unassociated with oil.

9. Examination of possible loss of product quality following an oil spill. This would be most likely to occur in Arctic charr. The rate of quality recovery in the Arctic is not known but it can be predicted to be temperature related.

10. As physical methods of clean-up have almost invariably been most effective in reducing oil contamination, the feasibility of physical clean-up in frozen seas should be examined in detail and new methods developed before there is need to utilize them.

11. Mechanisms should be established for the tracking of any oil spill that does occur and the investigation of its ultimate fate.

12. The development of social programs designed to increase public awareness of the real biological problems and foster self-regulation. Growth of industrial activity and the consequent increase in population will expose the Arctic to a wide variety of biological and chemical perturbations not previously experienced. Human activity will impose increased pressure on fish and mammal stocks through hunting, increased boat traffic and similar activities, and particularly through observation of wildlife using high speed boats and aircraft. Self-regulation implies the development of an ethical approach to the environment and its biota; all concerned must assume a high degree of personal responsibility for the maintenance of Arctic ecosystems.

13. An analysis of the risk factors involved in:
i) tanker design and navigational hazards;
ii) platform type and operational methods;
iii) pipeline design and operation.

These studies should subsequently be incorporated in a continuous monitoring program designed to test the original predictions and to guide future procedures for environmental protection. This is of greatest importance during the initial, expansion phases of oil production while opportunity still exists for the correction of design faults and operational techniques.

ACKNOWLEDGMENTS

The Working Group thanks Dennis Wright, Eric Gyselman and Bonnie Burns for their critical reading of the final manuscript, and Donna Glowacki for secretarial services.

REFERENCES

ADAMS, W.A. 1975. Light intensity and primary productivity under sea ice containing oil. Beaufort Sea Tech. Rep. 29.

BLAIR, S.R., and S.G.E. CARR. 1981. Major Canadian projects for Canadian opportunities. A report by the consultative task force on industrial and regional benefits from major Canadian projects in Canada to the year 2000 (June 1981). Available from Industry, Trade and Commerce, Government of Canada. 96 p.

BOEHM, P.D. 1981. Chemistry 2. Hydrocarbon chemistry 1980, Study Results. (BIOS) Baffin Island Oil Spill Working Report 80-2: 184 p.

BRADSTREET, M.S.W. 1982. Occurrence, habitat use and behaviour of seabirds, marine mammals, and Arctic cod at the Pond Inlet ice edge. Arctic 35: 28-40.

BRADSTREET, M.S.W., and W.E. CROSS. 1982. Trophic relationships at High Arctic ice edges. Arctic 35: 1-12.

BUNCH, J.N., R.C. HARLAND, and J. LALIBERTE. 1981. Microbiology, 1. Effects of oil on bacterial activity - - 1980 Study Results. (BIOS) Baffin Island Oil Spill Project Working Report 80-5: 68 p.

CLASBY, R.C., V. ALEXANDER, and R. HORNER. 1976. Primary productivity of sea-ice algae, p. 289-304. In D.W. Hood and D.C. Burrell (ed.) Assessment of the Arctic marine environment. Univ. Alaska Inst. Mar. Sci. Occas. Pap. 4.

CROSS, W.E. 1982. Under-ice biota at Pond Inlet ice edge and in adjacent fast ice areas during spring. Arctic 35: 13-27.

DEXTER, T. 1981. Probable statistics of accidental release of hydrocarbons, p. 17-26. CAFSAC 81/8. Consultation on the consequences of offshore oil production on offshore fish stocks and fishing operations.

DIAMOND, J.M. 1982. Man the exterminator. Nature (Lond.) 298: 787-789.

DUNBAR, M.J. 1960. The evolution of stability in marine ecosystems; natural selection at the level of the ecosystem. Am. Nat. 94: 129-136.

DUNBAR, M.J. 1968. Ecological development in polar regions: a study in evolution. Prentice-Hall, Englewood Cliffs, N.J.

DUNBAR, M.J. 1970a. Marine ecosystem development in polar regions, p. 528-534. In J.H. Steele (ed.) Marine food chains. Oliver and Boyd, Edinburgh.

DUNBAR, M.J. 1970b. On the fishery potential of the sea waters of the Canadian North. Arctic 23: 150-174.

DUNBAR, M.J. 1973. Stability and fragility in Arctic ecosystems. Arctic 26: 181-185.

DUNBAR, M.J. 1976. Man in the polar system, p. 11-32. In D.W. Hood and D.C. Burrell (ed.) Assessment of the Arctic marine environment. Univ. Alaska Inst. Mar. Sci. Occas. Pap. 4.

DUNBAR, M.J. 1977. The evolution of polar ecosystems, p. 1063-1076. In M.J. Dunbar (ed.) Adaptations within Antarctic ecosystems. Gulf Publishing, Houston, Texas, for the Smithsonian Institution.

DUNBAR, M.J. 1981. Physical causes and biological significance of polynyas and other open water in sea ice, p. 29-43. In I. Stirling and H. Cleator. Polynyas in the Canadian Arctic. Can. Wildl. Serv. Occas. Pap. 45.

DUNBAR, M.J. 1982. Arctic marine ecosystems, p. 233-261. In L. Rey (ed.) The Arctic Ocean: the hydrographic environment and the fate of pollutants. Comité Arctique International, Monaco.

FINLEY, K.J., G.W. MILLER, M. ALLARD, R.A. DAVIS, and C.R. EVANS. 1981. The belugas (Delphinapterus leucas) of northern Quebec: distribution, abundance, stock identity, catch history and management. Can. Tech. Rep. Fish. Aquat. Sci. 1123: v + 57 p.

FINLEY, K.J., and W.E. RENARD. 1980. Marine mammals inhabiting the Baffin Bay, North Water in winter. Arctic 33: 724-738.

FRAKER, M.A. 1979. Spring migration of the bowhead, Balaena mysticetus, and white whale, Delphinapterus leucas, in the Beaufort Sea. Can. Fish. Mar. Serv. Tech. Rep. 859: vi + 36 p.

GERACI, J.R., and T.G. SMITH. 1976. Direct and indirect effects of oil on ringed seals, Phoca hispida, of the Beaufort Sea. J. Fish. Res. Board Can. 33: 1976-1984.

GERACI, J.R., and T.G. SMITH. 1977. Consequences of oil fouling on marine mammals, p. 399-409. In D.C. Malins (ed.) Effects of petroleum on Arctic and Subarctic marine environments and organisms. Vol. II. Academic Press, New York.

GILFILLAN, E.S., and J.H. VANDERMEULEN. 1978. Alterations in growth and physiology of soft-shelled clams, Mya arenaria chronically oiled with Banker C from Chedabucto Bay 1970-76. J. Fish. Res. Board Can. 35: 630-636.

GRAINGER, E.H. 1977. The annual nutrient cycle in sea ice, p. 285-299. In M.J. Dunbar (ed.) Polar oceans. Arctic Institute of North America, Calgary, Alberta.

GRAINGER, E.H. 1979. Primary production in Frobisher Bay, Arctic Canada, p 9-30. In M.J. Dunbar (ed.) Marine production mechanisms. Cambridge University Press, Cambridge.

HORNER, R.A. 1977. History and recent advances in the study of ice biota, p. 269-283. In M.J. Dunbar (ed.) Polar oceans. Arctic Institute of North America, Calgary, Alberta.

JOHNSON, L. 1980. Arctic charr, p. 15-98. In E.K. Balon (ed.) Charrs, salmonid fishes of the genus Salvelinus. Dr. W. Junk, The Hague.

JOHNSON, L. 1981. The thermodynamic origin of ecosystems. Can. J. Fish. Aquat. Sci. 38(5): 571-590.

KAHN, A.E. 1966. The tyranny of small decisions: market failures imperfections and the limits of economics. Kyklos 19: 23-47.

LIVINGSTON, J.A. 1981a. Arctic oil: The destruction of the North. Canadian Broadcasting Commission, Toronto. 160 p.

LIVINGSTON, J.A. 1981b. The fallacy of wildlife conservation. McClelland and Stewart, Toronto. 111 p.

McALLISTER, D.E. 1975. Ecology of the marine fishes of Arctic Canada, p. II-51 - II-65. In Proceedings of the circumpolar conference on northern ecology, September 15-18, 1975, Ottawa. National Research Council, Ottawa.

MANSFIELD, A.W. 1958. The biology of the Atlantic walrus, Odobenus rosmarus rosmarus (Linneus) in the eastern Canadian Arctic. Fish. Res. Board Can. Manuscr. Rep. 653: 146 p.

MANSFIELD, A.W. 1971. Occurrence of bowhead or Greenland right-whale (Balaena mysticetus) in Canadian Arctic waters. J. Fish. Res. Board Can. 28: 1873-1875.

MANSFIELD, A.W. 1973. The Atlantic walrus, Odobenus rosmarus, in Canada and Greenland. IUCN Publ. New Series, Suppl. Pap. 39: 69-79.

MANSFIELD, A.W., T.G. SMITH, and B. BECK. 1975. The narwhal, Monodon monoceros in eastern Canadian waters. J. Fish. Res. Board Can. 32: 1041-1046.

MILNE, A.R. 1979. Oil, Ice and climatic change. Ministry of Supply and Services, Ottawa. 103 p.

MILNE, A.R., and R.H. HERLINVEAUX. 1973. Crude oil in cold water. Ministry Supply of and Services, Ottawa. 119 p.

ODUM, W.E. 1982. Environmental degradation and the tyranny of small decisions. Bioscience 32: 728-729.

OPHULS, W. 1977. Ecology and the politics of scarcity. W.H. Freeman, San Francisco. 303 p.

SANDERS, H.L. 1978. Florida oil spill impact on the Buzzards Bay benthic fauna: West Falmouth. Can. J. Fish. Aquat. Sci. 35: 717-730.

SANDERS, H.L., J.F. GRASSLE, G.R. HAMPSON, L.S. MORSE, D.S. GRANER-PRICE, and C.C. JONES. 1980. Anatomy of an oil spill: long-term effects of grounding of the barge Florida off West Falmouth. Massachusetts. J. Mar. Res. 38: 265-380.

SOUTHWARD, A.J. 1981. Life on an oily wave. Nature (Lond.) 294: 215-216.

SOUTHWARD, A.J., and E.C. SOUTHWARD. 1978. Recolonization of rocky shores in Cornwall after use of toxic dispersants to clean up the Torrey Canyon spill. J. Fish. Res. Board Can. 35: 682-706.

STIRLING, I., and H. CLEATOR. 1981. Polynyas in the Canadian Arctic. Can. Wildl. Serv. Occas. Pap. 45: 70 p.

THOMAS, L. 1979. The medusa and the snail. Bantam Books, New York. 146 p.

VANDERMEULEN, J. 1981. Oil behaviour offshore and concentrations of biota, p. 33-64. In Consultation on the consequences of offshore oil production on offshore fish stocks and fishing operations. CAFSAC Research Document 81/8, Bedford Institute of Oceanography, Dartmouth, N.S.

WATT, A.S. 1947. Pattern and process in the plant community. J. Ecol. 35: 1-22.

WILSON, E.B., and J.M. HUNT (ed.) 1975. Petroleum in the marine development. Workshop on inputs, fates and effects of petroleum in the marine environment. National Academy of Sciences, Washington D.C. 107 p.